

Production of Biodiesel from Rapeseed Oil in Greece

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Abstract

This work provides a detailed technoeconomical, political and environmental review of current Biodiesel production trends in Europe and Greece. Furthermore, detailed design of a biodiesel plant in Greece with a production capacity of 60,000 tonnes per year, using rapeseed as the raw material, is developed. The analysis includes finding a suitable region in Greece and determining the best process for the plant that minimises the overall cost. Detailed mathematical computations for design and costing of all equipment using the transesterification process are developed, which is then used to determine the financial costs of equipment, utilities, labour and the final product. By considering the price of rapeseed oil to be around 0.7 €/kg, the cost price (before taxation) for the proposed biodiesel comes to 0.715 €/litre, and the entire investment is able to break-even in three years. The analysis has also indicated that the cost price of biodiesel is lower than the current Greek market price of diesel. Moreover, recent Greek legislation (Law 3908/2011) is likely to improve the profit margin even further. Overall, based on the current economic downturn in Greece, such a project will have positive social and economic influences on society, in addition to its environmental advantages. The results of this research can provide a basis for political and industrial decision making.

Keywords

Biomass Technology; Renewable Energy; Cost-even Analysis

Introduction

Although the first “compression-ignition” engine fully powered by peanut oil in 1900, however, during the 20th century, the relative high price of biofuels to fossil fuels has resulted in the “disappearance” of vegetable oils as a fuel alternative. Due to resource depletion and the oil crisis in 1973 and 1979, interest in renewable energy sources has returned to the limelight again (Regnier., 2007). The first attempt at biodiesel production after the Arab oil embargo was in 1977, by the Brazilian scientist Expedito Parente, who managed to produce biodiesel through transesterification with ethanol. Following the same technique, engine-tested

biodiesel was patented in South Africa in 1983 (Bisen et al., 2010). Lateron, Austrian company *Gaskoks* managed to erect the first biodiesel plant in 1987. Currently, based on the sourcing of feedstock, there are four generations of biodiesel, which are described in Table 1.

TABLE 1 DIFFERENT GENERATIONS OF BIODIESEL BASED ON FEEDSTOCK TYPES AND MODE OF PRODUCTION

Generation	Feedstock and mode of production
First	Relies on crops giving sugars, starches and oil as their feedstock, such as rapeseed, cotton, corn, palm etc. The production of biodiesel is obtained by fermenting the sugars or with transesterification of fatty oils.
Second	Uses lignocellulosic biomass as feedstock and is produced through thermochemical routes or by breaking down cellulose with enzymes biodiesel.
Third	Produced from algae. Algae is produced from photosynthetic organisms and grown in the water by taking up light, CO ₂ and other nutrients. The algae oil can be used for producing biodiesel (alkyl esters)
Fourth	Either created using petroleum-like hydroprocessing, advanced bio-chemistry, or revolutionary processes like Joule's "solar-to-fuel" method.

Biodiesel has a golden or dark brown colour (depending on the feedstock). It is immiscible in water, has a high boiling point with low vapour pressure and is non-flammable under ambient pressure. It is even claimed that biodiesel contains 3.2 times the amount of energy it takes to produce (US Department of Energy., 2012). Generally, biodiesel can be legally blended with petroleum diesel and the most popular blends are shown in Fig. 1 (US Department of Energy., 2012).

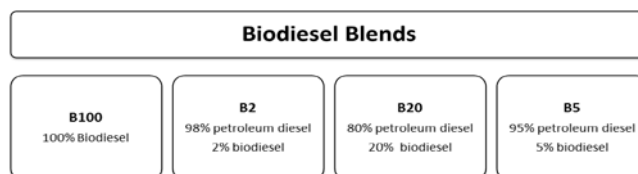


FIG. 1 MOST POPULAR BIODIESEL BLENDS^a

The higher the amount of biodiesel in the blend is, the

^a US Department of Energy, 2012

lower the emissions in the air with the exception of NO_x is, which increases as the ratio of biodiesel increases. Although B100 provides the best emission reductions compared with petroleum diesel, lower blends are also environmentally beneficial; for instance, B20 is able to reduce PM emissions by 10%, CO by 11%, and unburned HC by 21% (US Environmental Protection Agency, 2002; U.S. Department of energy, 2012).

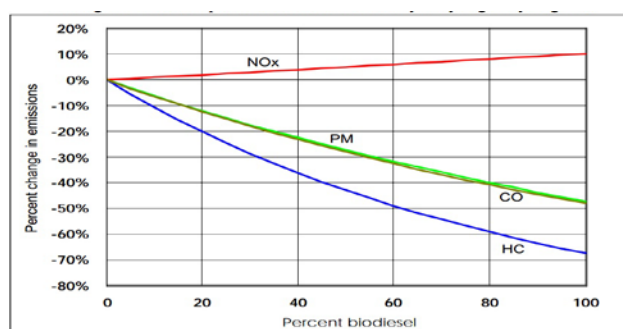


FIG. 2. AVERAGE EMISSIONS IMPACT OF BIODIESEL FOR HEAVY-DUTY HIGHWAY ENGINES^b

Moreover, compared to petroleum diesel, using biodiesel in a conventional petroleum diesel engine substantially reduces tailpipe emissions of unburned hydrocarbons (HC), carbon monoxide (CO), sulphates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter (PM) (US Department of Energy., 2012).

Europe is a powerful biodiesel producer, providing a total of 9.5 million tonnes of biodiesel in 2010. The European Union supports biofuels in order to reduce carbon footprint, replace fossil fuels, decrease imports of foreign fuels and boost rural areas. Top three EU biodiesel producers are Germany, France and Spain (shown in Fig. 3). From this figure, it is evident that there has been a rapid increase in annual production of Europe (Skarlis et al., 2007; Karagiannidis et al., 2007, EBB.Stastics, 2010).

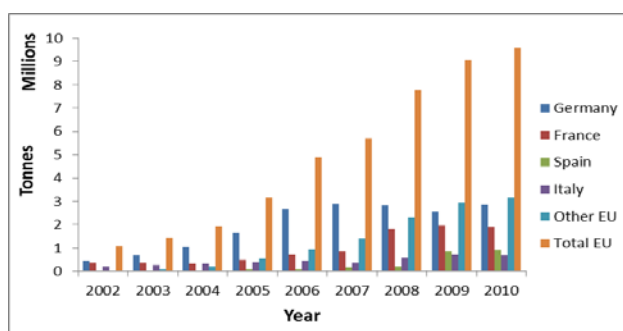


FIG. 3 BIODIESEL PRODUCTION IN EU 2002-2010^c

^b US Environmental Protection Agency, 2002

^c European Biodiesel Board, 2010

Directive 2003/30/EC or the 'Biofuel Directive' was adopted in 2003 by the European Parliament in order to promote biofuels for transport issues, and it set targets of 2% and 5.75% market share of biofuels by 2005 and 2010 respectively. The European Commission, in order to promote the cultivation of energy crops, introduced a 45€ per hectare programme for farmers in 2003, providing them with the motivation to grow the raw materials for biofuels production. All of the European countries have adopted the EU Directives, where tax exemptions and biofuel obligations are the basic principles for the European countries to implement with the legal framework objectives (Karagiannidis et al., 2007).

Greece is one of the first EU countries that provided tax exemptions policy for biofuels. According to the the *Hellenic Republic Ministry of Development* in 2006, Greece's most popular biomass raw materials for the industrial sector were waste wood, straw and cotton residues. The total annual consumption was estimated at around 150k tonnes of oil equivalent (toe), whereas Greek households used to use a total of 0.7 M toe of wood annually for heating and cooking purposes. Table 2 provides a typical summary of Greece's energy profile.

TABLE 2 GREECE COUNTRY AND ELECTRICITY PRODUCTION PROFILE IN 2012^{d,e}

Country Profile		Electricity Production Profile (2001)	
Population	10.8 Million(2011)	Fossil Fuel	94.5%
Area	131,957 km ²	Hydro	3.8%
Total Primary Energy Supply	29M toe (2009)	Nuclear	0%
Electricity Production	58.79 billion kWh (2011)	Other renewables	1.7%

On December 13th 2005, the Greek constitution voted through and adopted Act 3423/2005 for the "Introduction of biofuels and other renewable fuels in the Greek market". Next, a programme for the allocation of biofuel quantities was set up and linked with the establishment of the Biofuels Distribution License. This was for companies that wished to be involved in the production and selling of biofuels in Greece. Finally, the national target of 5.75% for 2010 was set for national biofuel usage, as shown in Table 3. (Myrsini Christou., 2011). Under Act 3423/2005, each participant has the right and the obligation to distribute specific quantities of pure biofuels and

^d Central Intelligence Agency World Factbook, 2012

^e International Energy Agency, 2012

blends on the Greek market. A provision incorporated in Article 34 of Act 3340/2005 provides full excise duties exemption from the following quantities of pure biodiesel: First call: 51,000 m³ (in 2005), second call: 91,000 m³ (published by the end of 2005) and third call: 114,000 m³ (published in December 2006). Under the 1st call, 2,500 tonnes of pure biodiesel were allocated to Hellenic Biopetroleum S.A. Under the 2nd call, 16 companies submitted applications for tender. The quantities were allocated to 12 biodiesel producers and 2 biodiesel traders. The last call for 114,000 tonnes biodiesel was published in 2006 by the *Greek Ministry of Development*.

TABLE 3 ESTIMATION OF BIODIESEL REQUIRED FROM 2005 TO 2010^f

Year	Estimated Automotive Diesel Consumption (thousands of tonnes)	Biodiesel used (%)	Biodiesel Required (tonnes)
2005	3,707	2.00	120,442
2006	3,800	2.50	154,329
2007	3,892	3.00	189,678
2008	3,984	4.00	258,883
2009	4,077	5.00	331,157
2010	4,169	5.75	389,424

According to National Reports on the promotion of the use of biofuels or other renewable fuels for transport in Greece for the period 2005-2010, *Greece's most promising future investments will be biodiesel and bioethanol*. The first attempt at the production and distribution of biodiesel in Greece was made in December 2005 and no biofuels had been distributed or consumed before this time (Hellenic Republic Ministry of Development, 2006b). During this trial, biodiesel was blended with automotive diesel from refineries and industries to produce petroleum products. The biodiesel produced was around 3000 tonnes and by 2007 this had increased to 100,000 tonnes. Currently, there are thirteen biodiesel plants in Greece (shown in Table 4 and Fig 5).

TABLE 4 BIODIESEL COMPANIES IN GREECE 2010^g

Company	Origin of quantity of pure biodiesel	Capacity (tonnes)
Pavlos N. Pettas S.A. Biodiesel Ltd.	Patra Industrial Area	99,000
	Mygdonia Park Municipal District, Thessaloniki	21,000
Agroinvest S.A.	Achladi Municipal District, Fthiotida	230,000
ELVI	Kilkis	79,000
Staff Colour Energy S.A. ELIN Biofuels S.A.	Larissa Industrial Area	11,000
Vioenergeia Papantoniou S.A.	Volos Industrial Area	73,300
	Chalkidiki	9,000

^f Myrsini Christous, 2011^g Hellenic Republic, Ministry of Development, 2010

Ekkokistiria-klostiria Voreiou	Komotini	6,600
VertOil S.A.		
Mil Oil Hellas S.A.	Kilkis	10,450
NEWENERGY S.A.	Thessaloniki	9,900
GF ENERGY S.A.	Serres	21,000
MANOS S.A.	Korinthos	99,000
	Volos	33,000

FIG. 5 BIODIESEL PLANTS ALLOCATION^h

Rapeseed is considered the third most important oil producing plant after soybeans and palm oil in Greece. Table 5 compares the efficiency of the five most popular energy crops in Greece. It can be concluded that rapeseed and sunflower have the highest efficiency in biodiesel production which is between 50 to 100 kg/stremma (unit for measuring the land area in Greece; equal to 0.1 hectare) (Intelligent Energy Europe a).

TABLE 5 FEEDSTOCK FOR PRODUCING BIODIESEL PER YEARⁱ

Raw Material	Crop Efficiency kg/stremma*	Biodiesel Efficiency kg/stremma	Biodiesel Efficiency litres/stremma
Sunflower	150 – 300	50 – 100	58 – 116
Rapeseed	150 – 300	50 – 100	58 – 116
Cynara	100 – 150	24 – 36	28 – 41
Cardunculus			
Soy-bean	120 – 160	17 – 23	20 – 27
Cotton	160 – 240	27 – 41	32 – 48

* 10 stremma = 1 hectre

Cultivation of the rapeseed plant generates two products: rapeseed oil (from the seed) and rapeseed flour (from the residue). The rapeseed oil is the only type of oil that meets 100% EU specifications for biodiesel production. Rapeseed flour is a product rich in proteins (34%) and can be used as an animal food as well, partial replacing soybeans, and hence reducing the cost of animal food production. On average 30-37 kg of rapeseed can be produced by cultivating one

^h Myrsini Christous, 2011ⁱ Greece Centre for Renewable Energy Sources, 2000-2006

hectare of land, which corresponds to the production of 10-13 kg of biodiesel (Intelligent Energy Europe a; CRES, 2000-2006; Rigalos et al., 2008).

In this paper, we will analyse a 60,000 tonnes per year biodiesel production plant in Greece assuming local production of raw material. The analysis includes detailed mathematical computations on the technical equipment of the industrial plant and also contains cost analyses for the technical equipment, utilities, by-products and the final product. The results of this research can provide a basis for political and industrial decision making.

Methodology

The first step for this research is to find a suitable area for the plant's facilities. One of the most critical factors we consider at this point is the accessibility of the arable land for the cultivation of rapeseed, which is the raw material. The capacity of the biodiesel plant, the amounts of utilities and raw materials used and any other quantities such as the catalyst were calculated using the commercial software package, Aspen Hysys. The production process through transesterification was studied and explained in this work. The total cost of the installation was calculated. For the purpose of the computations, data will be extracted from Aspen Hysys. Distillation columns will be examined separately by using the McCabe-Thiele method in order to calculate the number of trays. Due to the presence of the highly polar components, methanol and glycerol, both the non-random two liquid (NRTL) and universal quasi-chemical (UNIQUAC) thermodynamic/activity models were recommended to predict the activity coefficients of the components in a liquid phase (Hyprotech Ltd., 2000). Detailed descriptions of these models were provided by Gess et al. (1991). The total cost of the installation and the payback periods will be evaluated to determine if this is going to be a good and lucrative investment in general.

Modelling and Design

The modelling section was divided into three sub-sections: location-allocation, the chemical process and the production process of biodiesel. In the first sub-section the region of Greece that is most suitable for the cultivation of the required rapeseeds was allocated. In the second sub-section, the chemical process for producing biodiesel was studied. Finally, the simulation results were presented.

Location Allocation

Traditionally, the location-allocation problem has been a well-established research area within the field of Operation Research (OR). Melo et al. (2009) conducted an extensive review of the role of facility location models within the supply chain. The authors divided the investigation into two objectives: namely, facility location and supply chain management. There are many papers found addressing the topic of single location layer with single commodity. (Sahin and Süral, 2007; Melkote and Daskin, 2001; Barahona and Jensen, 1998). Thus for this research, we will start by finding a suitable area in Greece for the installation of the biodiesel plant.

Large (around 45,000 ha) and easily accessible quantities of raw materials are important requirements for this area, as this will reduce the cost of transportation from the cultivation site to the plant. Similarly, other raw materials such as methanol, acid and base catalysts should be readily available near the site of the plant as well. Finally, the biodiesel produced should be accessible for distribution, and lack of competition in the area is essential for establishing this new industry. Taking all these criteria into account, the region of Southwest Greece (shown in Fig.6) is the most suitable region for the investment. This part of Greece is called Aitolioacarnania and it consists of mountains (Acarnanian Mountains), rivers (Acheloos, Evinos and Ermitsa etc.) and rich fertile valley for cultivation. According to the national Statistic Department of Greece around 500,000 stremma of unused land is readily and easily available for rapeseed cultivation in Aitolia-Acarnania.



FIG. 6 GREECE, AITOLOACARNANIA

Based on land availability, in this research it was assumed that the capacity of the biodiesel plant will be 60,000 tonnes per year, that the average number of working days for any industry in Greece is 344 days and that the plant operates for 24 hours a day. Thus, the total number of hours is 8,256 hours per year.

$$Q_{\text{biodiesel}} = 7.267 \text{ tonnes /hour} = 7,267 \text{ kg/hour} \quad (1)$$

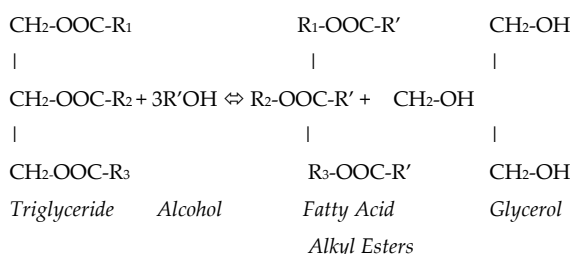
Using the average biodiesel efficiency of 70 kg/stremma summarised in Table 5 above, it can be computed that:

$$\text{Required stremma} = 85,714.3 \text{ ha/year} \quad (2)$$

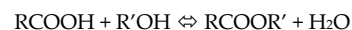
Since rapeseed produces double crops per year, the required hectares are divided into 42,857.14 ha or 428,571.4 stremma, which is a bit less than the available 500,000 stermma; it is reasonable to use a number less than 500,000 stermma to account for any error in the assumptions.

Chemistry of Biodiesel Production

Transesterification is the main chemical reaction for the production of biodiesel. Currently, it is considered to be the most efficient process because of the low temperature (65°C) and pressure (20psi) requirements for the process, as well as the high and direct conversion rate (98%) of methyl ester (Skarlis et al., 2007). The overall process is made up of a sequence of three consecutive and reversible reactions. During the first reaction, a triglyceride which is the main content of the vegetable oil and animal fats, reacts with an alcohol in the presence of a catalyst, producing a mixture of fatty alkyl esters and glycerol.



Triglyceride is also known as triacylglycerol, triacylglyceride, or TAG. It is an ester composed of a glycerol bound to three fatty acids with R₁, R₂, and R₃ denoting long hydrocarbon chains. Methanol or ethanol can be used as alcohols in the reaction but methanol is predominant in commercial applications because it is cheaper and offers greater ease of downstream recovery of the unreacted alcohol. The catalyst can be either acid or base depending on the content of the feedstock. In the case where waste cooking oils are going to be used as feedstock, high in free fatty acids (FFA), the reaction of esterification will take place in the presence of an acid catalyst in order for the conversion into biodiesel to take place, as shown.



Since base catalysts are much more efficient for transesterification than acids, they are the natural choice when no esterification reaction is required to convert FFA.

Free fatty acids and water always produce negative impacts during the process as both of them together can cause soap formation (increase viscosity, difficulties in glycerol separation etc.). There are three known base catalysts which can be used in the transesterification: Sodium Hydroxide, Potassium Hydroxide and Sodium Methoxide (also known as Sodium Methylate). Sodium Hydroxide (NaOH) has much slower dissolution in Methanol compared to Potassium Hydroxide and Sodium Methoxide. Potassium Hydroxide (KOH) is more expensive than NaOH due to its higher potential yields for biodiesel with lower waste disposal cost. Sodium Methoxide (NaOCH₃) is more expensive than the hydroxides but a lower concentration of NaOCH₃ is required to achieve a good reaction. It is estimated that 70% of US biodiesel production relies on Sodium Methoxide (Thane., 2008).

An acid catalyst can be used in the pre-treatment stage for esterification of FFA and then followed by transesterification (with base catalyst). There are two common acid catalysts for esterification: Hydrochloric acid (HCl) which has the ability to access the sugar of multiple feedstocks with little water use, and Sulphuric acid (H₂SO₄) which is much cheaper than the first one; HCL currently costs around 100€/ton (U.S. Department of energy, 2012).

Process Description

At the beginning of the process, both methanol and NaCOH₃ are mixed together, and put with the rapeseed oil to the reactor so the transesterification reaction takes place. After the transesterification, the biodiesel and glycerol should be separated and methanol should be recovered. In this work Sodium Methoxide (NaOCH₃) and Hydrochloric acid (HCL) (instead of H₂SO₄ and KOH) are used as catalysts. The system produces biodiesel from an alcohol (methanol or ethanol) and one or several different oil feedstocks. H₂SO₄ is used to convert any FFA by esterification. Such a commercial scale process can either operate in a continuous mode or a semi-continuous mode.

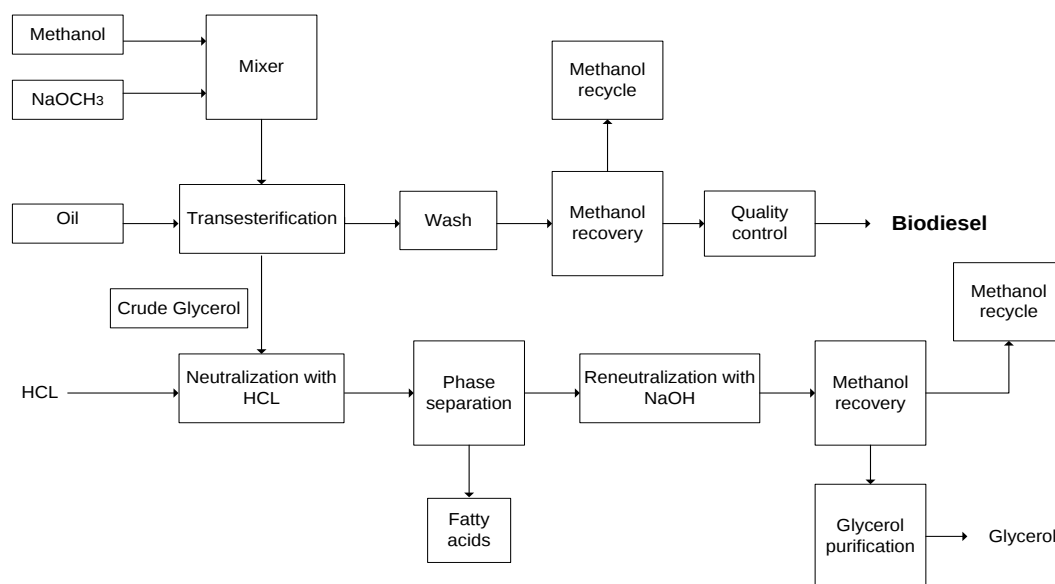


FIG. 7 GENERAL PROCESS STEPS FOR THE BIODIESEL PRODUCTION

Overall, the process consists of six major components.

1. The Acid-alcohol esterification pre-treatment and water/acid removal units: Esterification (complete conversion of FFA) where the molar ratio of alcohol to oil is 6:1, catalyst to oil ratio is 1 wt%, temperature is around 60-70°C, reaction lasts up to 1.5 hours and water and acid are to be removed-by washing with glycerol-before entering the next step.
2. Base alcohol transesterification units: Transesterification (90-98% conversion of TAG) where the molar ratio of alcohol to oil is 6:1, catalyst to oil ratio is 1 wt%, temperature is around 45-60°C, reaction lasts up to 1 hour.
3. Biodiesel drying unit: for the product to meet the quality standards, crude biodiesel needs to be washed with water to remove the catalyst and finally purified by distillation and drying.
4. Catalyst recovery unit: Catalyst has to be neutralised by acid in this stage.
5. Alcohol recovery unit: Unreacted alcohol is separated by distillation and then recycled.
6. Glycerol unit: Glycerol may be recovered at different grades of purity depending on the intended use and the accepted level of costs.

As can be seen from the process flowsheet (Fig. 8), there are two sequential transesterification reactors, R-501 and R-502. The reactions are both conducted at 60°C. The first one is continuously fed with rapeseed oil, methanol and sodium methoxide.

The glycerol- rich product from the first reactor enters

a continuous centrifuge, FF-101, in order for the glycerol to be removed and sent to the mixing tank, M-101. Methanol, sodium methoxide and unreacted substances coming from FF-101(stream 7) are the feed for the second reactor. The mixture of methyl esters, glycerol, unreacted substrates and catalyst coming out of the bottom of R502 (stream 9) enters a second continuous centrifuge FF-102. The glycerol-rich bottom product from FF-102 goes to the glycerol recovery section, whereas the top product is sent to the biodiesel refining section in order to be purified and dehydrated. The top product of FF-102 is washed with water to neutralise the catalyst and convert any soap to free fatty acids. Another centrifuge, FF-103, is then employed to separate the biodiesel from the rest of the liquid phase. The bottom output of FF-103 is sent to the mixing tank, M-101. The top product, which contains mostly water and biodiesel, enters a vacuum dryer, VD-101, where water and biodiesel are separated. The glycerol from the reactors and the biodiesel wash are gathered in the process tank, V-202, and treated with HCL to convert soaps to free fatty acids; these are then removed with the centrifuge, FF-104.

This fatty acid is disposed of as sewage for the whole industry. The remaining glycerol is neutralised with sodium hydroxide (NaOH) and then distilled in alcohol recovery distillation, T-101, in order to reduce its water content. Methanol is recovered by another alcohol recovery distillation, and T-102, is recycled in the transesterification process. The fraction of water in the glycerol process is recycled in the wash operations (Haas et al., 2006).

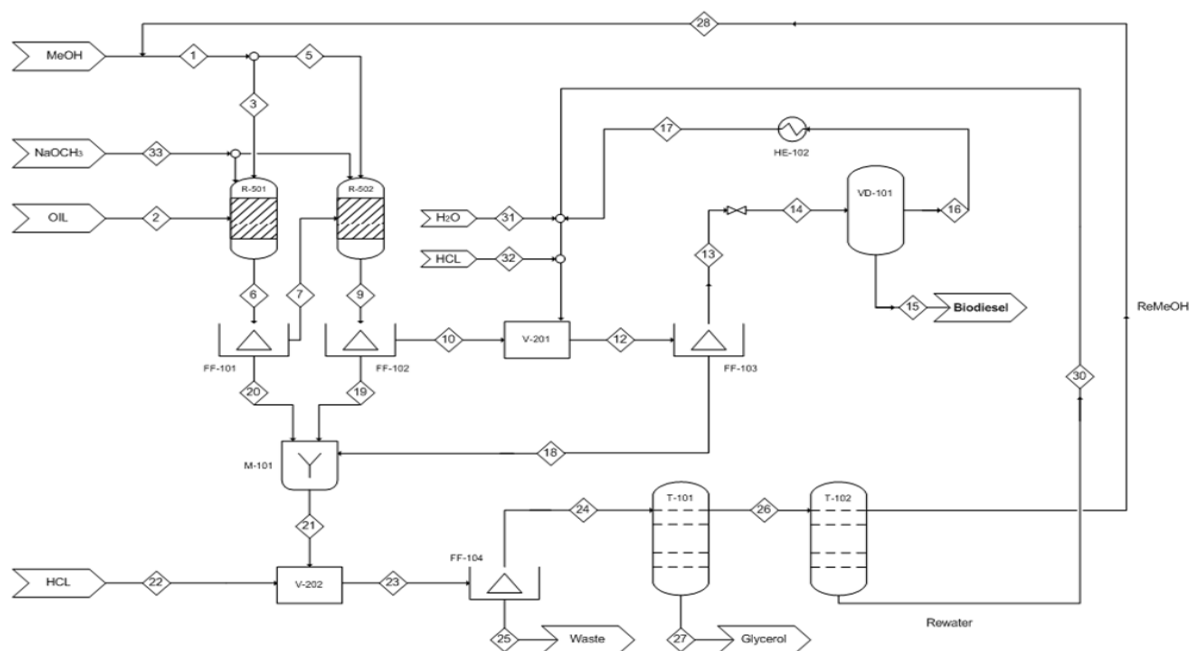


FIG. 8 FLOWSHEET FOR THE PRODUCTION OF BIODIESEL FROM RAPESEED OIL

Result and Discussion

The result of the process simulation is presented in Table 6 with details of stream characteristics which enable a precise calculation of the operational requirement. Again, due to the presence of the highly polar components, methanol and glycerol, both the non-random two liquid (NRTL) and universal quasi-chemical (UNIQUAC) thermodynamic/activity models were recommended to predict the activity coefficients of the components in a liquid phase (Zhang et al., 2003; Hyprotech Ltd., 2000). Some unavailable interaction parameter coefficients, such as those for methanol/methyl-oleate, glycerol/methyl-oleate and sulphuric acid with any other component, were estimated using the UNIQUAC liquid-liquid equilibrium module in HYSYS.

Cost Analysis

A provision of the biodiesel production cost is presented in this section. The costs are broken down into capital costs, which consists of the equipments to be used in the plant (e.g. biodiesel tank, rapeseed tank, methanol tank, centrifugal, mixer etc.), as well as operation costs which are the raw material, catalyst, steam, electricity and labour costs.

Raw Material and Catalyst Costs

In Europe, over the last decade, the price of rapeseed oil decade has ranged from 0.4 €/kg to 1.1 €/kg (International Monetary Fund, 2012). Thus for this research, the price of rapeseed oil is set at 0.7 €/kg.

From Table 4.1 (stream 2), the necessary amount of rapeseed oil for production is 7,083 kg/h. As the industry runs for 344 days per year and 24 hours per day, the total cost of the rapeseed is 40,934,073.6€ annually. The base catalyst (NaOCH_3) to oil ratio is 1 wt% (Haas et al., 2006). Thus 70.83 kg per hour of NaOCH_3 is required by the plant. That gives a total annual cost of 3,192,695.97€ per year based on the cost of the base catalyst being 6.71€/kg. An acid catalyst (HCL) is used to neutralise the base catalyst and to breakdown fatty acids. HCL is added into the system in streams 22 and 32. In stream 22, there is 1.11 kg-mole HCL per hour, which gives rise to 19.98 kg and 70.83 kg per hour of HCL being needed for streams 22 and 32 respectively. Assuming the cost of HCL is 0.107 €/kg, the total cost of the acid catalyst required is 80,220.83€ per year.

Steam and Electricity Costs

Steam is required mainly in the reactors and distillation columns. It is known from our simulation that 1.4 GJ steam is needed to produce 1 tonne of biodiesel. Thus 81,527.6 GJ of steam is required per year for the plant. This comes to 403,317.04€ based on a unit cost of 4.947€ per GJ of steam. Similarly, electricity is required in the reactors and centrifugal vessels. Again, it is known from process simulation that 30 kW electricity is required to produce 1 tonne of biodiesel, which gives a total amount of 1,747,020 kW per year for electricity needs, which in turn costs 142,207.43€ per year, based on 0.0814€ per kW of unit electricity cost.

TABLE 6 STREAM CHARACTERISTICS

Stream	Temperature (°C)	Pressure (kPa)	Mass flow (kg/h)	Molar flow (kgmole/h)	Oil	MeOH	Biodiesel	Glycerol	H ₂ O	HCL	Waste (Fatty acid)
1	60	140	1,538	48		48					
2	60	140	7,083	8	8						
3	60	140	1,230	38.4		38.4					
5	60	140	308	9.6		9.6					
6	60	140	8,314	46.4	0.8	16.8	21.6	7.2			
7	60	140	7,429	32.5	0.8	10.1	21.6				
9	60	140	7,737	42.1	0.1	17.5	23.7	0.7			
10	60	140	7,439	34.3	0.1	10.5	23.7				
12	60	140	8,560	104.3	0.1	1.1	23.7		79.4		
13	60	140	8,870	113.7	0.1	10.5	23.7		79.4		
14	11.5	1	8,560	104.3	0.1	1.1	23.7		79.4		
15 (biodiesel)	100	1	7,083	23.8	0.1	0.0009	23.5		0.2		
16	100	1	1,527	80.5		1.1	0.2		79.2		
17	75	140	1,527	80.5		1.1	0.2		79.2		
18	60	140	310	9.5		9.5	0.02				
19	60	140	298	7.8		7	0.02	0.7			
20	60	140	885	13.9		6.7	0.02	7.2			
21	60	140	1,493	31.2		23.2	0.1	7.9			
22	60	140	60	3.4						2.3	1.1
23	60	140	1,554	34.6		23.2	0.07	7.9	2.3	1.1	0.07
24	60	140	1,526	34.1		23.2		7.9	3		
25	60	140	28	0.5					0.4		0.07
26	74	140	770	24.7		23.2			1.5		
27	198	140	756	9.4		0.0046		7.9	1.5		
28	36	30	742	23.2		23.2			0.0015		
30	60	70	28	1.5			0.023		1.5		
31 (H ₂ O)	75	140	100	5.6				5.6			
32 (HCL)	75	140	71	3.9							3.9
33 (NaCOH ₃)	60	140	71	1.7							

Storage Tank and Process Tank Costs

According to the simulation results, stream 15 which ends at the biodiesel storage tank has a Standard Ideal Liquid Volume Flow of 8.0148 m³ per hour. The tank must be able to store the produced biodiesel for four weeks, so the necessary volume of the individual tank is 5,770.66 m³. In order to avoid overflow, an extra 20% is added to this volume. The new volume of the individual biodiesel tank therefore comes to 6,924.79 m³. Based on the new volume, the total cost comes to 717,092.49€. This is the cost of the installed equipment as of 2012, with the correction factor for stainless steel being 2.4. In the same way, the costs of the oil, methanol, glycerol, catalyst and HCL tanks have been calculated (Koukous, 2008-2009).

The stream which ends at the process tank, V-202, has a Standard Ideal Liquid Volume Flow of 1.7718 m³/h. Thus the volume is 1.7718 m³, if the resident time in the tank is an hour. Again, in order to avoid the risk of overflow, the volume of the tank is increased by 20%. The new volume of the tank comes to 2.13 m³.

However, the volume for the process tank needs to be $5 \text{ m}^3 \leq V_{\text{tank}} \leq 80 \text{ m}^3$. Since the calculated volume is lower than this constraint, we will use the lower limit of 5 m³ instead. Using the correction factor for stainless steel of 2.4, the cost of the installed tank comes to be 22,546.98€. We calculate the costs of the other process tank, V-201 similarly (Koukous, 2008-2009).

Centrifugal and Pressure Viessel (Mixer) Costs

Stream 6 which ends at the continuous centrifuge, FF-101, has a Standard Ideal Liquid Volume Flow of 8.6090 m³/h and, similar to the process tank, the centrifuges must comply with the restriction of $1 \text{ m}^3 \leq Q \leq 50 \text{ m}^3$. Thus the cost for the continuous centrifuge, FF-101 comes to 75,049€. Using the same methodology, the costs of FF-102, FF-103, FF-104 are calculated respectively (Koukous, 2008-2009). According to the result from the simulation, the flow rate in mixer, M-101 is 1.65814 m³/h and because the resident time in the tank is 1 hour, the volume of the vessel is calculated to be 1.65814 m³. To avoid the risk of overflow, the volume of the tank is increased by 20%.

Thus the new volume is 1.9897 m³. Based on this, the diameter of the vessel is 1.082 m and the height is 2.164 m. However, the diameter and height should comply with the restrictions where $0.305 \text{ m} \leq D \leq 3.05 \text{ m}$ and $1.22 \text{ m} \leq H \leq 30.5 \text{ m}$ respectively. The cost of the vessel comes to 7,525€. The cost of the installed equipment is 31,830€, using $F_{BM}=4.23$, $F_M=1$, $F_P=1$.

Vacuum Dryer Costs

The result of the simulation for the stream characteristics of the vacuum dryer is shown in Table 7. For the design of the vacuum dryer, which contains gas and liquid, the required volume of the retained liquid V_L will be 1.44 m³, assuming the resident time t equal to 10 minutes. Then the required diameter, according to the speed of the gas and since the vessel operates without a filter, u_v is 11.14 m/s and the diameter of the vacuum dryer is 2.28 m. The height of the liquid, H_L will be 0.23 m. Based on this result, the height of the segment which is available for gas, H_v , is calculated taking into account the following constraints.

$$H_v > 1.67 \text{ m}$$

$$3 \leq (H_L + H_v)/D \leq 5$$

In this case study, since the ratio is less than 3, it is assumed that H_v is increased until the ratio is equal to 3. Thus the value of $H_v = 8.5 \text{ m}$ is used. This will satisfy both of the constraints in (3). The total height of the vessel turns out to be 8.73 m, and the cost of the vessel is 63,658€. Finally, the cost of the installed equipment is 269,270€, where $F_{BM}=4.23$, $F_M=1$ and $F_P=1$

TABLE 7 VACUUM DRYER DATA

Parameter	Value
Liquid flow rate (L)	7,033 kg/h
Density of liquid (ρ_L)	815.26 kg/m ³
Steam flow rate (V)	1,527 kg/h
Density of gas (ρ_v)	0.006115 kg/m ³

Distillation Column Costs

The number of trays corresponding to the second distillation column is calculated by using the McCabe-Thiele method. From simulations, the following data is obtained: (1) mole fraction of water in bottom product, $X_R = 0.0153$; (2) mole fraction of feed, $X_F = 0.9397$; and (3) mole fraction of methanol in distillate, $X_D = 0.9999$. The minimum reflux ratio required to achieve the product specification is 0.6665 and the real reflux ratio is calculated as 0.54. Based on this result, we calculate the surface area of the tray to be 0.9399 m², and the diameter of the column to be 1.17 m, using the data in

Table 8. Based on the calculation, the real number of trays needed for the distillation column is 11, the distance between the trays is 0.6 m and the height of the column is 6.6 m. The weight of the column comes to 1,374.5 kg. Using the above result, the cost of the installed equipment without trays is 85,240€ as of 2012, where $F_{BM}=4.23$, $F_M=1$, $F_P=1$. The cost of the tray is 15,880€. Thus the final total cost for the distillation column T-101 is 101,120€. The same principle is applied to calculate T-102 as well.

TABLE 8 DISTALLATION COLUMN DATA

Parameter	Value
Steam flow rate (V)	8,324 kg/h
Density of gas (ρ_v)	1.5091 kg/m ³
Speed of gas (μ_v)	1.63 m/s
λ	0.88

Reactor and Heat Exchanger Costs

The flow rate for the sequential transesterification reactor, R-501 is 8.7350 m³/h. With a conservative assumption of the resident time in the reactor being 1 hour; the volume comes to 8.7350 m³. In order to avoid the risk of overflow, the volume of the tank is increased by 20%, giving a new volume of 10.482 m³. Putting these values together, the cost of the reactor itself is 40,844€, and the cost of the installed equipment is 169,900€ as of 2012, where $F_{BM}=4.16$, $F_M=1$, $F_P=1$. Based on the simulation results, the exchanged heat in the heat exchanger, HE-402, is equal to $Q = 958.1 \text{ kW}$, and $\Delta T_{LM} = 55.6^\circ\text{C}$, where $T_{h,i} = 100^\circ\text{C}$, $T_{h,o} = 75^\circ\text{C}$, $T_{c,i} = 25^\circ\text{C}$ and $T_{c,o} = 40^\circ\text{C}$. The rotation surface is calculated as 12.58 m² and the cost of the reactor alone is 9,799€ as of 2012. Finally, the cost of the installed equipment is 32,239€, where $F_{BM}=3.29$, $F_M=1$, $F_P=0$, $F_d=1$.

Labour Costs

Koukous, (2008-2009) provided an extensive list of the workforce needed in a plant based on the type and quantity of every unit of operation, using the same principle. In total, 16 workers are required per shift, and the total labour costs comes to 260,000€ per year for the overall project (including maintenance). The detail is listed in Table 9.

TABLE 9 WORKFORCE NEEDED FOR EACH UNIT OF OPERATION

1 heat exchanger	$1 \times 0.1 = 0.1$
2 distillation columns	$2 \times 0.5 = 1.0$
4 centrifugal viessels	$4 \times 0.2 = 0.8$
1 mixer	$1 \times 0.3 = 0.3$
1 vacuum dryer	$1 \times 0.2 = 0.2$
2 reactors	$2 \times 0.5 = 1.0$

Table 10 shows the summary of annual cost of

materials, utilities and workforce.

TABLE 10 TOTAL ANNUAL COST OF RAW MATERIALS, UTILITIES, AND WORKFORCE

Material	Required Quantity	Annual Cost €
Raw Materials		
Rapeseed Oil	58,477.3 ton/year	40,934,073
Methanol	6,571.8 ton/year	1,504,942
Base Catalyst (NaOCH ₃)	584.8 ton/year	3,192,696
Acid Catalyst (HCL)	753.2 ton/year	80,221
Water	11,095.4 ton/year	594.7
Total Cost: 45,712,526.7€		
Utilities		
Steam	81,500 GJ/y	403,317
Electricity	1,747,000 kW	142,208
Total Cost: 545,525€		
Workforce		
Workers	16	260,000
Total Cost: 260,000€		

Break-even Analysis

In order to assess the economic feasibility of investing in a 60,000 tonnes biodiesel plant, a break-even analysis is conducted. This is a technique used to find the break-even point (BEP), at which costs or expenses are equal to revenue. A profit or a loss has not been made, although opportunity costs have been “paid”, and capital has received the risk-adjusted, expected return (David and Boldrin., 2008). The objective of the analysis is to compare the cost price (before taxation) of the biodiesel produced by the plant against the cost price of diesel sold in Greece, to see the profitability of our biodiesel plant in the long run. The cost price of the biodiesel is also compared against the WTI crude oil price, to see if the crude oil price gives availability for the investment of the biodiesel technology.

Currently in Greece, a number of taxes are imposed on diesel that is to be sold in the market, and they are applied as follows (Greece Ministry of Development, 2012):

1. 412€ per 1000 litres of diesel fuel.
2. Additional 0.5% of tax on the total amount in step 1.
3. 0.20 €/m³ of fuel tax on top of the total amount in step 2.
4. 1.2% of the initial diesel cost (i.e. before step 1).
5. Finally, 23% of VAT is added to the total sum of steps 3 and 4 before diesel is sold in the Greece market.

In 2011, Greece passed the Investment Incentives (Law 3908/2011), which replaces the previous incentive

(Law 3299/2004). Under the new incentive scheme, the following incentives are available (Greece Ministry of Development, 2012; KPMG, 2011):

- Tax relief: Exemption from payment of income tax on pre-tax profits.
- Cash grants provided by the State that cover part of the expenses of the investment project.
- Leasing subsidies provided by the State that cover part of the payable instalments related to the leasing of new equipment. However, the leasing subsidies do not exceed a seven-year period.

Since there is no income tax on pre-tax profits, no other costs (e.g. income tax) will be considered in the break-even analysis. In this research, it is assumed that the break-even periods are three years (i.e. the biodiesel plant will start to make profit after three years).

Biodiesel Price vs. Diesel Price in Greece

In order to compare the biodiesel price of the proposed plant against the diesel price in Greece, the cost price of the biodiesel is first calculated. The total cost for the first three years of operation is 142,768,689€, and the proposed biodiesel plant is able to produce 199,728,061.5 litres of biodiesel (1 tonne biodiesel = 1,143.25 litres) during this period. Based on the above results, the cost price for producing the biodiesel in our proposed plant is 0.715 €/litre.

Fig. 9 shows the average Greece diesel cost price for the period of 10 years (01/2002 – 12/2012). (European Commission, Statistics and Market observatory, 2012) The cost price of diesel in Greece is between 0.25€ to 0.93€. Based on Fig. 9, the cost price of diesel has risen above our proposed biodiesel price (0.715 €/litre) since the beginning of 2011. The price of diesel in Greece is rising with respect to time. Thus it can be concluded that the use of biodiesel has great potential in Greece, and the deployment of such a biodiesel plant is profitable based on the proposed biodiesel cost price and the incentives given by the government and the states.

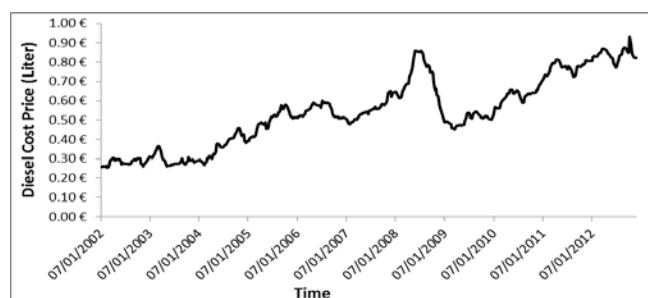


Fig 9. UNIT COST PRICE vs. DATE FOR BIODIESEL IN GREECE

Fig. 10 shows the relationship between Greece diesel cost price and the WTI crude oil price over the period of 10 years (01/2002 – 12/2012). From the figure, it can be concluded that the price of the diesel in Greece is linearly proportional to the WTI crude oil price. Using the proposed biodiesel cost price of 0.715 €/litre as calculated in 5.1, we try to find the break-even point of the crude oil price, which comes to 92.21 \$/barrel.

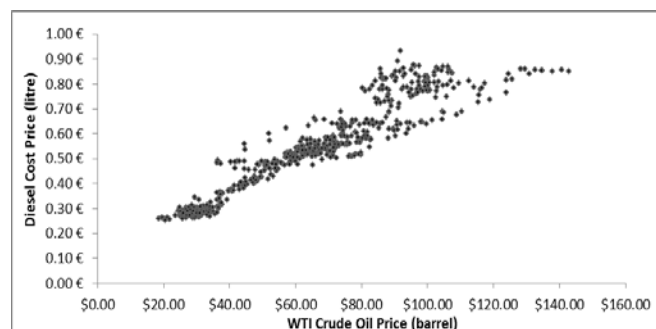


FIG 10. CORRELATION BETWEEN DIESEL COST PRICE, CRUDE OIL PRICE IN GREECE AND TIME^j

However, assuming that tax is implemented for regular diesel but not biodiesel, the profit for biodiesel can be further improved. Fig. 11 shows the relationship between the Greece diesel market price and the WTI crude oil price from 2005 to 2012. Based on the plot, it can be concluded that the market prices for diesel and crude oil are correlated. Using our proposed biodiesel price, the break-even point of the crude oil comes to 29.74 \$/barrel.

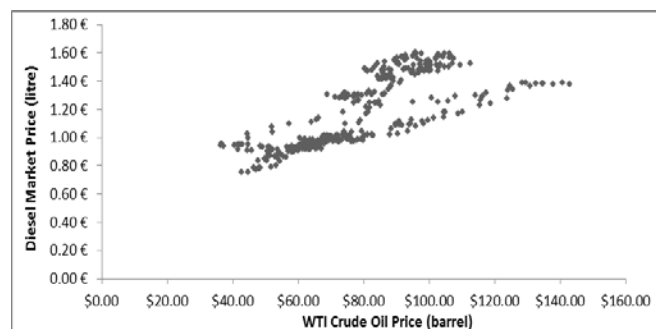


FIG 11. CORRELATION BETWEEN DIESEL MARKET PRICE, CRUDE OIL MARKET PRICE IN GREECE AND TIME^k

Fig. 12 below shows how the WTI crude oil price has changed over time, for the same period of 10 years (US Energy Information Administration, 2012). From this plot, it can be concluded that the crude oil price has risen gradually since 2002. Based on the break-even

analysis of 92.21 \$/barrel for crude oil price, investment in the biodiesel plant is still profitable in the last two years (01/2011 – 12/2012), as the average cost of crude oil is 94.49 \$/barrel. However, looking at the immediate future, the crude oil price is close to our break-even point. With the incentives given by the government and the state, investment in the biodiesel plant will still be profitable in Greece.

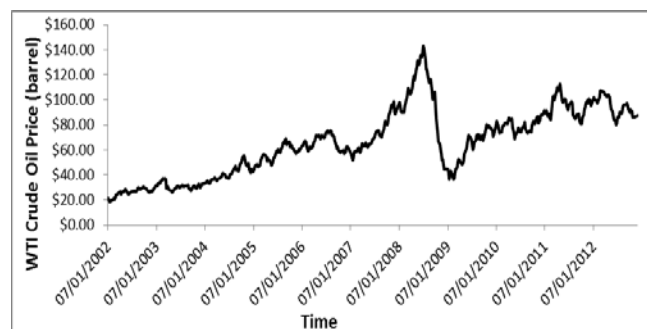


FIG 12. CORRELATION BETWEEN WTI CRUDE OIL PRICE AND TIME^l

Conclusions

In this research, we looked closely at the EU policies regarding biofuel production, and more specifically, Greece's potential in investing in a biodiesel plant. Based on Greece's geographical characteristics and its feedstock production capability, we have investigated a technoeconomic feasibility of a biodiesel plant with a capacity of 60,000 tonnes per year using rapeseed oil as the feedstock. Based on the overall results, it can be concluded that Greece has very good potential for investing in rapeseed to produce biodiesel in the long run. Although the expenses of the investment are high, it is still profitable to invest in biodiesel technology in Greece. Based on our simulation and calculation, the current diesel as well as the crude oil market, the proposed biodiesel plant is able to break-even in three years. With the help of government and state incentives, this investment is definitely profitable in the long run, as the price of both diesel in Greece and crude oil will be more expensive in future. The investment also brings social benefits such as job opportunities, directly and indirectly, economic benefits based on the current correlation between the diesel price in Greece and the crude oil price internationally, and environment benefits, based on the reduction in greenhouse gases.

At the same time, although rapeseed oil is the

^j Adopted from: European Commission, Statistic and Market Observatory, 2012; US Energy Information Administration, 2012

^k Adapted from: European Commission, Statistic and Market Observatory, 2012; US Energy Information Administration, 2012

^l Adapted from: US Energy Information Administration, 2012

preferred energy crop in Greece, even higher biodiesel yields can be achieved if cultivation of different seeds such as sunflowers, cotton, etc. can be used. Since waste cooking oils are generated by households every day, it will further improve the biodiesel production rate and quantity if these are used as well. Such investments can be planned by multiple parties, with the government and state as the promoters.

Due to the current economic status of the country, such an investment may be withheld until the situation improves. Government and policy are also factors which will significantly influence the biodiesel industry, to the extent that such an industry in Greece will be policy driven. However, an industry project of such scale will provide opportunities for improvement for the nation as a whole.

The development of such industries requires major breakthroughs in technologies, successful commercialisation, and the development of infrastructure. On the other hand, its clean emissions profile and ease of use make biodiesel one of the fastest growing alternative fuels in the world. With the subsidies given by the government and the state, the cost of biodiesel is competitive with that of petroleum diesel in Greece. The future of biodiesel lies in the world's ability to produce renewable feedstocks such as vegetable oils and fats to keep the cost of biodiesel competitive with petroleum, without supplanting land necessary for food production, or destroying natural ecosystems in the process. Creating biodiesel in such a manner will allow this clean, renewable, and cost effective fuel to help ease the world through increasing shortages of petroleum, while providing economic and environmental benefits well into the 21st century.

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